CONFIDENTIAL

RESEARCH DEPARTMENT

The effect of ionospheric non-linearity on medium-frequency transmissions from Aldabra

RESEARCH REPORT No. RA-18

UDC 621. 391. 812. 63: 621.391. 827 .4 1968/20

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

CONFIDENTIAL

RESEARCH DEPARTMENT

THE EFFECT OF IONOSPHERIC NON-LINEARITY ON MEDIUM-FREQUENCY TRANSMISSIONS FROM ALDABRA

Research Report No. RA-18
UDC 621.391.812.63 1968/20
621.391.827.4

P. Knight, B.A., M.I.E.E.

Head of Research and Development

This Report is the property of the British Broadcasting Corporation and may not be reproduced or disclosed to a third party in any form without the written permission of the Corporation.

This Report uses SI units in accordance with B.S. document PD 5686.

Research Report No. RA-18

THE EFFECT OF IONOSPHERIC NON-LINEARITY ON MEDIUM-FREQUENCY TRANSMISSIONS FROM ALDABRA

Section	Title	Page
	SUMMARY	1
1.	INTRODUCTION	1
2.	ONE 3 MW TRANSMISSION	2
3.	TWO SIMULTANEOUS 1·5 MW TRANSMISSIONS	2
4.	CONCLUSIONS	4
5.	REFERENCE	4

May 1968

Research Report No. RA-18
UDC 621.391.812.63 1968/20
621.391.827.4

CONFIDENTIAL

THE EFFECT OF IONOSPHERIC NON-LINEARITY ON MEDIUM-FREQUENCY TRANSMISSIONS FROM ALDABRA

SUMMARY

Because it has been proposed to use a very high effective radiated power at Aldabra, effects caused by ionospheric non-linearity cannot be disregarded. These effects include reduction of the received signal together with its distortion. When two transmissions are radiated simultaneously, non-linearity also causes them to cross-modulate in the ionosphere. The magnitudes of these various effects are examined in this report.

1. INTRODUCTION

The effect of ionospheric non-linearity on a high-power m.f. night-time sky-wave broadcasting service has been discussed in general terms in an earlier report.[1] The present report refers specifically to the effect of ionospheric non-linearity on transmissions from a proposed m.f. station at Aldabra. At the time of writing plans for this station are in abeyance.

Aldabra is situated about 800 km from the East coast of Africa and the station is intended to serve East and Central Africa at night by means of the sky wave. It is proposed to install four 750 kW transmitters which will either be combined into a single 3 MW transmitter, or grouped into pairs radiating 1·5 MW simultaneously on two frequencies. With both arrangements the transmitters will be fed to a four-radiator directional aerial system beamed in a westerly direction. Although it has now been decided to use radiators approximately $\lambda/4$ high, the use of tall radiators (approximately $\lambda/2$ high) having a higher gain was also being considered when the calculations described here were being carried out; results for both types of radiator are given for completeness.

Although Aldabra is situated near the Equator, the European electron-density and collision frequency profiles shown in Fig. 4 of Reference 1 have been used for the calculations; consultation with current workers on the subject has indicated that this assumption is reasonable. Transverse propagation is assumed, since propagation towards the West from Aldabra approximately satisfies this condition. The magnetic dip latitude is 42° south and the gyromagnetic frequency 0·92 MHz. At this dip latitude ordinary and extraordinary waves are excited in roughly equal proportions on east-west paths. Fig. 7 of Reference 1 applies approximately to the situation at Aldabra and shows the attenuation increases which would occur at the bottom of the E-layer if each mode were radiated with an effective radiated power (e.r.p.) of 7·5 MW; the curves for an e.r.p. of 30 MW show the attenuation increases occurring at the peaks of very low modulation frequencies. The curves indicate that the use of frequencies within ± 200 kHz of the gyromagnetic frequency would be undesirable. All subsequent calculations were therefore confined to the frequency range 1·1 to 1·5 MHz, since no frequencies below the gyromagnetic frequency were available.

Ionospheric non-linearity effects are important only at the first reflection point and are, of course, greatest when short hops are involved. Since the distance to the nearest point on the African mainland is about 800 km, ionospheric reflection points less than 400 km from the transmitter need not be considered.* Calculations were made for first-hop lengths of 800 and 1600 km, the latter distance being near the maximum for which a 1-hop mode makes the main contribution to receiver input voltage. These showed that non-linear effects would be serious only when the first ionospheric reflection point is 400 to 500 km from the transmitter. The effect of non-linearity is therefore important at distances between 800 and 1000 km; it is also important between 1600 and 2000 km, since these latter distances are beyond the effective range of the 1-hop mode and are best served by the 2-hop mode, whose first ionospheric reflection point is relatively close to the transmitter.

Fig. 9 of Reference 1 shows attenuation increases calculated by the ray-tracing technique for westerly paths from Aldabra when the first ionospheric reflection point is 400 km from the transmitter; it has been reproduced here as Fig. 1, the power levels corresponding to a 3 MW transmitter having been added. Also indicated are the attenuation increases occurring at the modulation peaks when the transmitter is modulated at a very low audio frequency.

---

* The 2-hop mode has been disregarded for distances less than 1600 km because it suffers much higher attenuation than the 1-hop mode and therefore does not contribute greatly to the received signal. It also tends to penetrate the E-layer at the upper end of the m.f. band.

We now consider in more detail the magnitude of the effects which are expected to occur when all transmitters are combined to radiate on a single frequency and also when two transmissions are radiated simultaneously.

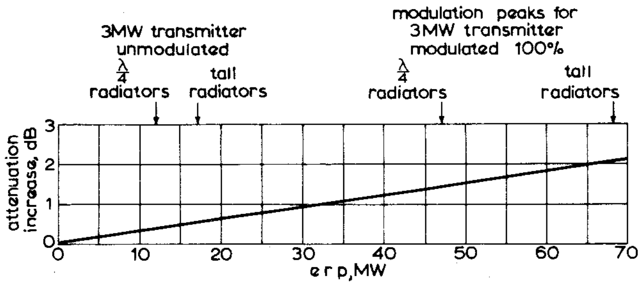

Fig. 1 - Increase of attenuation due to non-linearity

2. ONE 3MW TRANSMISSION

Fig. 1 shows that the increase in the attenuation of an unmodulated 3MW transmission is 0·4dB if λ/4 radiators are used and 0·6dB if tall radiators are employed. Limiting values for the reduction of the fundamental component of the modulation, which is equal to the increase in receiver signal-to-noise ratio, are given in Table 1, the transmission being assumed to be 100% modulated. The way in which this reduction varies with modulation frequency is shown in Fig. 2(*a*), the ionospheric time constant $1/G\nu_0$ being assumed to be 1·25 ms.

TABLE 1

Reduction of Fundamental Component of Modulation Frequency

	λ/4 radiators	Tall radiators
Low modulation frequencies	1·5 dB	2·25 dB
High modulation frequencies	0·6 dB	0·9 dB

Fig. 2(*b*) shows the second and third harmonic levels which occur when the transmission is 100% modulated. The curves of Fig. 2 were calculated from Equations (22), (23) and (24) of Reference 1.

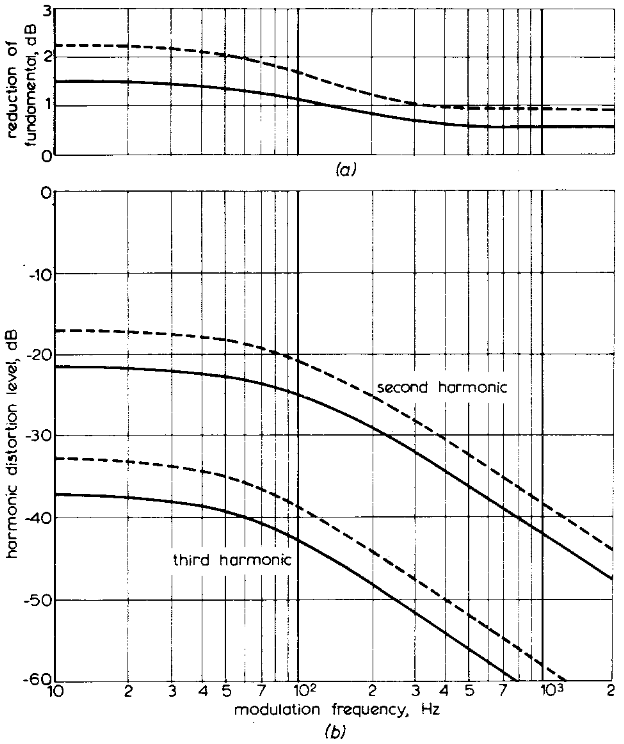

Fig. 2 - Self-distortion of one 3MW transmission

(*a*) Reduction of fundamental
(*b*) Harmonic distortion

——— Four λ/4 radiators
– – – – Four tall radiators
Modulation depth 100%

Cross-modulation of other transmissions over Africa is unlikely to be serious because of the distance between Aldabra and the African mainland; the nearest ionospheric reflection point will be at least 800 km from Aldabra. Since this is twice as far from Aldabra as the reflection point assumed for the calculation of Fig. 1, an estimate of the cross-modulation may be made by assuming that the attenuation increase δA_{U} is one-quarter of the value given by Fig. 1. Equation (19) of Reference 1 then shows that the fundamental cross-modulation percentages at very low audio frequencies are 2·3% and 3·5% for λ/4 and tall radiators respectively, when the Aldabra transmitter is 100% modulated. In passing it should be noted that the field strength in the ionosphere 800 km from Aldabra will be about the same as that 100 km from a 1 MW transmitter driving a single radiator; thus cross-modulation levels in Africa should be no greater than those currently experienced in Europe.

3. TWO SIMULTANEOUS 1·5MW TRANSMISSIONS

Non-linearity reduces each individual transmission when unmodulated by either 0·2 or 0·3 dB, depending on whether λ/4 or tall radiators are used. The reduction of the fundamental component of the wanted modulation is obtained by adding Equations (18) and (22) of Reference 1. Limiting values for the reduction of the fundamental when both transmissions are modulated 100% are given in Table II, the variation with modulation frequency being similar to that shown in Fig. 2(*a*).

TABLE II

Reduction of Fundamental Component of Modulation Frequency

	λ/4 radiators	Tall radiators
Low modulation frequencies	1·1 dB	1·6 dB
High modulation frequencies	0·6 dB	0·9 dB

The second and third harmonic levels of the wanted transmissions, calculated from Equations (23) and (24) of Reference 1, are about 6 dB lower than the corresponding levels for a single 3 MW transmission (shown in Fig. 2(*b*)) because δA_U has been halved.

The cross-modulation between the two transmissions is given by Equations (26) and (27) of Reference 1 and depends to a small extent on the modulation depth of the wanted transmission. Since the subjective effect of cross-modulation is greatest when the wanted transmission is unmodulated, only this case is considered here. Fig. 3(*a*) shows the cross-modulation levels which occur when the unwanted transmission is modulated 100%.

Intermodulation levels occurring when the unwanted transmission is modulated 100% were calculated from Equations (28) and (29) of Reference 1 and are shown in Fig. 3(*b*). These levels, relative to the level of the wanted modulation, are independent of the modulation depth, and almost independent of the modulation frequency, of the wanted transmission.

The cross-modulation levels shown in Fig. 2 are higher than the values which would normally be regarded as acceptable. Since the highest levels occur at low audio frequencies, however, it is an advantage to attenuate the lower audio frequencies before modulating the transmitter. Such attenuation is, in fact, normal practice in the BBC External Services and the programme feeds received at Aldabra will have been subjected to this attenuation in the U.K., the frequency response of a typical programme input shaping network being shown in Fig. 4. The effect of this network is to change the modulation levels of individual frequencies by the amount shown in Fig. 4. First-order cross-modulation and intermodulation terms are also changed by the same amount and second-order terms by twice the amount. The resulting cross-modulation and intermodulation is shown in Fig. 5, which may be compared with Fig. 3.

The subjective effect of the residual cross-modulation arising when standard programme input shaping networks are used was investigated in the laboratory. Both the wanted and unwanted modulations were passed through shaping networks and limiters typical of those used at BBC transmitters, so that both modulations resembled the programme feeds which would be received at Aldabra from the U.K. The shaping networks had the frequency response shown in Fig. 4 and the limiters gave 16 dB of compression. The unwanted modulation was also passed through a de-emphasis network having a time constant of 1·26 ms to simulate the ionospheric time constant, thereby reducing cross-modulation at the higher audio frequencies.

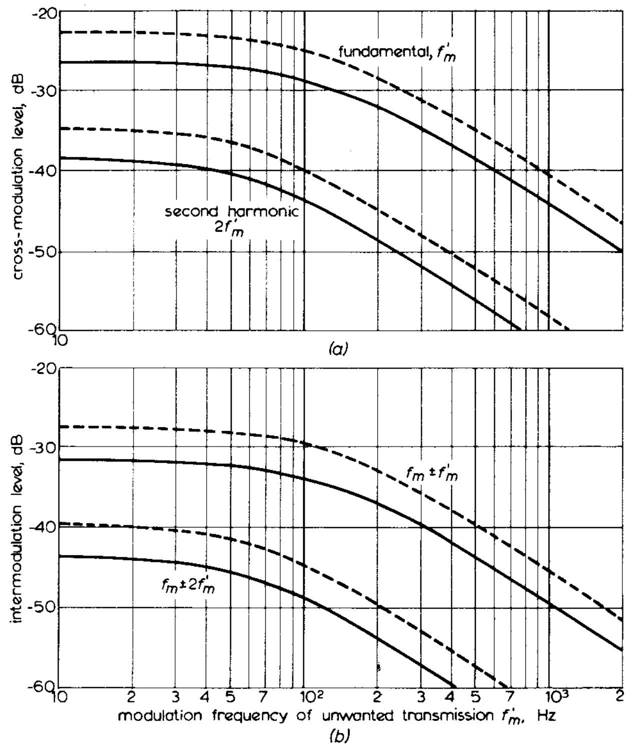

Fig. 3 - Interaction between two 1·5 MW transmissions radiated simultaneously

(*a*) Cross-modulation
(*b*) Intermodulation

——— Four λ/4 radiators
– – – – Four tall radiators
Unwanted transmission modulated 100%

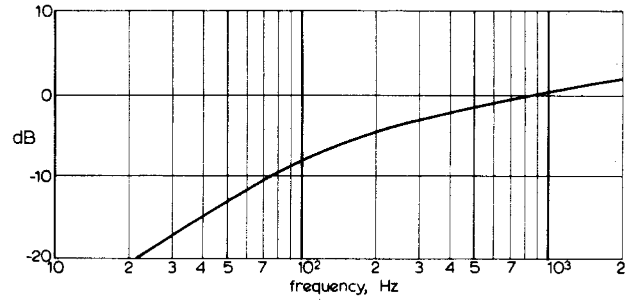

Fig. 4 - Frequency response of programme input shaping network

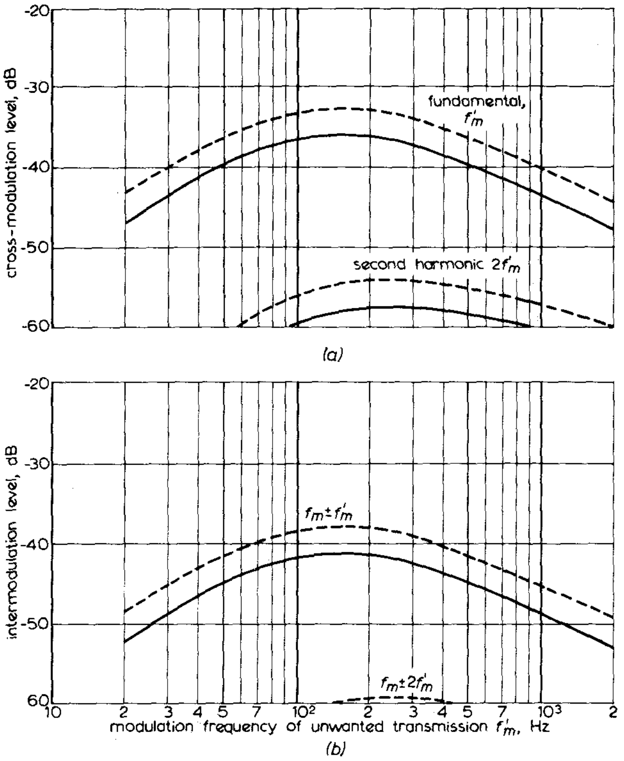

Fig. 5 - Interaction between two 1·5 MW transmitters with programme input shaping networks

(*a*) Cross-modulation
(*b*) Intermodulation

———————Four λ/4 radiators
– – – – – – – –Four tall radiators
Unwanted transmission modulated 100%

The relative gains of the two audio-frequency channels were adjusted so that the unwanted modulation was 42 dB lower than the wanted modulation at 800 Hz; this corresponds to the expected effect when λ/4 radiators are used and is the ratio given by the unbroken (fundamental) curve of Fig. 3.* The two audio-frequency signals were added and used to modulate a typical domestic receiver, so producing the characteristic reduction of the higher modulation frequencies which results from receiver intermediate-frequency response. The unwanted modulation heard in the internal loudspeaker of the receiver was graded as 'just perceptible.'

4. CONCLUSIONS

When a single 3 MW transmission is radiated from Aldabra, ionospheric non-linearity will cause the effective strength of the signal received in some parts of the service area to be about 1 dB less than it would be if ionospheric non-linearity were absent. This figure applies to the useful part of the audio-frequency spectrum. When two 1·5 MW transmissions are radiated simultaneously, they will cross-modulate each other in the ionosphere and audio-frequency intermodulation products will also be generated. The most important effect is the cross-modulation, but its subjective effect will be no worse than 'just perceptible' provided the programme feeds have passed through standard programme input shaping networks before transmission.

The effects due to ionospheric non-linearity will be greatest in the nearest parts of the African mainland (800 to 1000 km from Aldabra) and also at distances between 1600 and 2000 km since the latter are not well-served by the 1-hop mode. The reduction of signal strength is unimportant at the closer range of distances, however, because here the field strength is high. Cross-modulation of other services on the African mainland by transmissions from Aldabra will be no greater than cross-modulation currently experienced in Europe with existing l.f. and m.f. transmitters, because of the relatively large distance between Aldabra and the African coast.

5. REFERENCE

1. Ionospheric non-linearity. BBC Research Department Report No. RA-17, Serial No. 1968/19

---

* Because shaping networks are present in both channels, Fig. 3 (not Fig. 5) gives the relative level of the two modulations. Fig. 5 gives the absolute level of the unwanted modulation.

JMP

Printed by BBC Research Department, Kingswood Warren, Tadworth, Surrey